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United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/7-79-098b
April 1979

EPA

Proceedings: Symposium on Coal Cleaning to Achieve Energy and Environmental Goals (September 1978, Hollywood, FL) - Volume II

EPA--600/7-79-098b-Vol.2

DE83 007323

Interagency Energy/Environment R&D Program Report

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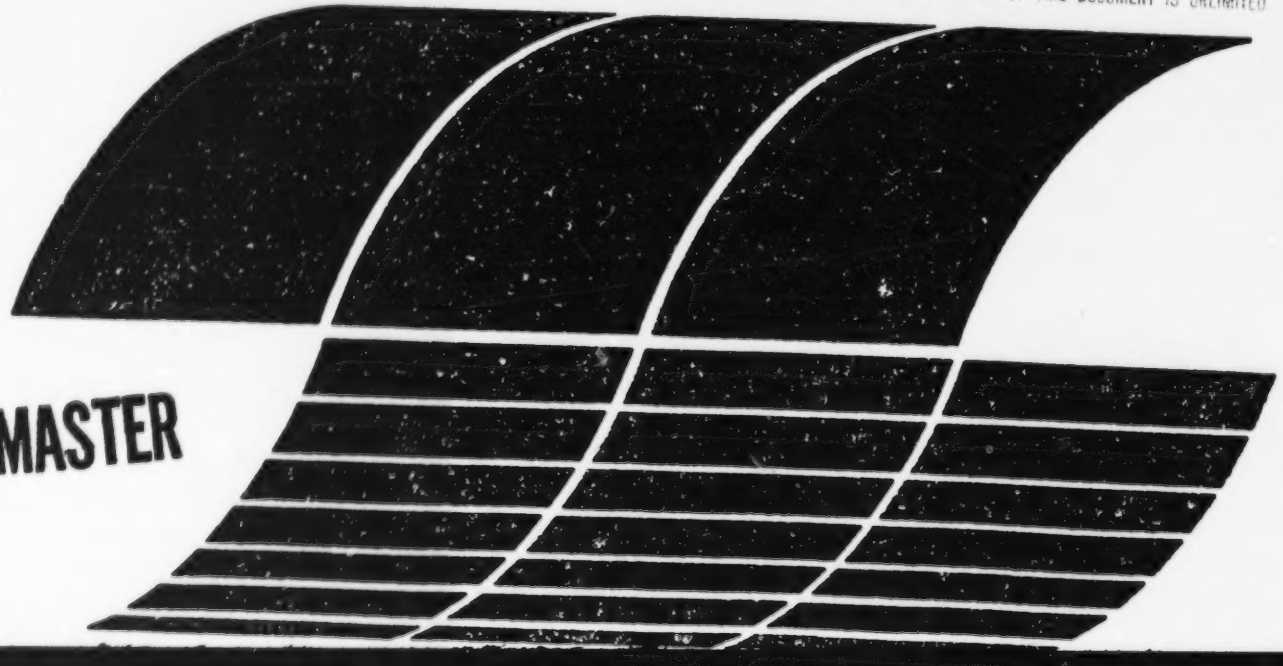

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SURVEY OF COALS TREATED BY OXYDESULFURIZATION

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ABSTRACT

The feasibility of using only compressed air and water at elevated temperature to reduce the sulfur content of coal has been demonstrated in autoclave experimentation at the Pittsburgh Energy Technology Center for various coals from most of the major coal basins in the United States. This air/water oxydesulfurization consistently removes in excess of 90 percent of the pyritic sulfur and has the potential for reducing the organic sulfur content by up to 40 percent. The sulfur liberated from coal by this reaction is present in the aqueous effluent as dilute sulfuric acid which can be neutralized with limestone. Under certain reaction conditions pyrite forms a jarosite intermediate which reports as organic sulfur in chemical analysis. Extent of organic sulfur removal and loss of heating value increase with temperature in the range 170°-200°C.

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INTRODUCTION

Precombustion removal of sulfur and minerals from coal by physical/chemical cleaning is a developing technology that will provide alternate approaches to the electric utility industry and industrial boiler installations for complying with EPA New Source Performance Standards (NSPS) and future revisions without relying totally on flue gas desulfurization (FGD) (Friedman and Warzinski, 1977). These approaches could vary from physical/chemical cleaning alone to combining it with FGD. A combination approach could potentially reduce capital and operating costs by increasing reliability, reducing duplication of equipment needed to achieve present reliability, improving feedstock uniformity, reducing trace elements and ash constituents responsible for deposits and corrosion, and reducing sludge disposal problems. (Engdahl and Rosenberg, 1978; Balzhiser, 1978).

The only methods of coal cleaning practiced commercially are physical methods which utilize density differences and surface properties to achieve separation of coal and associated minerals. At an acceptable level of fuel value loss physical cleaning removes only accessible pyritic sulfur, leaving behind that which is finely

divided throughout the coal matrix and sulfur chemically bound to the organic coal matrix. Therefore, only a small percentage of coals can be brought into compliance using only physical cleaning. On the other hand the selective chemical removal of sulfur from coal is capable of approaching complete pyritic sulfur elimination and, depending on the process, removal of the reactive organic forms of sulfur in coal.

A variety of chemical cleaning processes are under development and have been reviewed in the literature. (Friedman and Warzinski, 1977; Oder, et.al., 1977; Versar, Inc., 1978; Meyers, 1977). This report deals with the developmental research of one of these techniques, air/water oxidative desulfurization (termed Oxydesulfurization).

Air/water oxidative desulfurization has been demonstrated in autoclave experiments for various coals representative of the major U.S. coal basins (Friedman and Warzinski, 1977). The reaction proceeds most effectively at temperatures of 150 to 200° C at a total system pressure of 3.5 to 10.4 MPa (500 to 1500 psig). Above 200° C, coal and product heating value losses become substantial due to the oxidative loss of carbon and hydrogen. The pyritic sulfur solubilization reactions are typically complete (95 percent removal) within 15 to 40 minutes at temperature; however, significant organic sulfur removal requires residence times as long as 60 minutes at the higher temperatures. The principal products of the reaction are sulfuric acid and iron oxide. Several samples of coals treated by air/water oxidative desulfurization were exhaustively extracted with toluene which was

then removed on a rotary evaporator. No elemental sulfur was detected.

Although little is known of the organic sulfur reactions (Friedman, LaCount and Warzinski, 1977), the pyrite/air oxidation reaction in aqueous media has been studied extensively by Vracar and Vucurovic (1970, 1971, 1972) in relation to producing sulfuric acid from pyrite for use in ore extraction. The following reactions were proposed for finely ground pyrite based upon conditions similar to those used for coal by Friedman and Warzinski (1977).

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4 \quad (1)$$

$$2FeSO_4 + 1/2O_2 + H_2SO_4 \rightarrow Fe_2(SO_4)_3 + H_2O \quad (2)$$

$$Fe_2(SO_4)_3 + nH_2O \rightarrow Fe_2O_3 \cdot (n-3)H_2O + 3H_2SO_4 \quad (3)$$

$$3Fe_2(SO_4)_3 + 14H_2O \rightarrow 2Fe_3(SO_4)_2(OH)_5 \cdot 2H_2O + 5H_2SO_4 \quad (4)$$

Above 140° C no elemental sulfur was observed. Small amounts of the basic jarosite salt (reaction 4) were formed at lower pH and temperature. Vracar and Vucurovic (1972) observed that for a 20 gm/l pyrite slurry under the conditions 200° C, 0.61 to 1.02 MPa (74-133 psi) oxygen partial pressure, and 3 hour residence time, pyrite was completely converted to sulfuric acid and iron oxide. At temperatures below 200° C small amounts of unreacted pyrite, ferrous, and ferric sulfate were present. The pyrite reaction rate was found to be first order in unreacted pyrite with an activation energy of 51.0 kJ/mole (12.2 kcal/mole). In a more recent kinetic study, Slagle (1978), using an Upper Freeport coal under similar conditions, also found the pyritic sulfur reaction to be first order in unreacted pyrite with an activation energy of 46.7 k J/mole (11.2 k cal/mole). The organic sulfur data were

scattered, but were fitted to a zero order rate expression with an activation energy of 78.7 k J/mole (18.8 k cal/mole). Broader reviews of pyrite oxidation and coal sulfur oxidation have been published by Meyers (1977) and Slagle (1978) covering reaction temperatures and pressures outside the ranges utilized for air/water oxydesulfurization.

EXPERIMENTAL

Air/water Oxydesulfurization coal screening experiments consist of treating a slurry of 35 gm of 200 x 0 mesh coal in 100 ml distilled water contained in a glass, teflon, or stainless steel liner inserted into a one liter, magnetically stirred, 316 stainless steel autoclave. The autoclave system can be operated in batch or semibatch modes. In the batch mode the autoclave containing the slurry is pressurized with air at room temperature to the desired oxygen partial pressure and subsequently heated by a jacket type heater to reaction temperature at a rate of approximately 3^{o} C/minute. The slurry is agitated at 900 to 1000 RPM with a 3.175 cm diameter gas dispersion turbine-type impeller. Reaction temperature, once reached, is stabilized to within $\pm 2^{o}$ C by a proportioning temperature controller and manually operated internal water cooling coil. After the desired residence time at reaction temperature, the cooling coil is used to quench the reaction by lowering the temperature at a rate of approximately 50 to 60^{o} C/minute. When the autoclave reaches room temperature a gas sample is taken and the product slurry removed.

The product slurry is filtered through Whatman 541 paper in a Buchner funnel and washed with distilled water until the pH of

the filtrate tests 4 to 5 with litmus paper, normally requiring about one liter of distilled water. The product coal is extracted on a Soxhlet with distilled water until all soluble sulfates are removed, as determined with barium chloride. Analyses of the initial filtrate and Soxhlet washings indicate greater than 90 percent of the soluble sulfur compounds are removed from the product coal in the first wash. The coal sample is finally vacuum dried at 110° C for approximately 2 hours, weighed, and sent for analysis.

In the semibatch mode of operation a constant air flow in the range of 52 to 208 liters/hour (STP) is used to maintain constant system pressure and essentially constant oxygen partial pressure throughout the reaction. In order to minimize the evaporation and loss of water from the slurry, approximately 70 ml of distilled water is placed between the reactor wall and the liner while charging the autoclave to help saturate the effluent gas. The autoclave is purged with nitrogen at atmospheric pressure, closed off, and heated to reaction temperature. When this temperature is attained the autoclave is rapidly pressurized with air to the desired operating pressure and the continuous air flow started. The reaction is quenched by terminating the air flow and using the internal cooling coil. Gas samples are normally taken during and at completion of the reaction. The product workup is identical to that of the batch mode.

RESULTS AND DISCUSSION

Twenty-four coals have been treated by air/water oxidative desulfurization. Data for sulfur removal are given in Table 1, and the balance of the ultimate analyses are in Table 2. All twenty-four coals, unless noted in Table 1, were treated for one hour at the temperature indicated under either 5.6 MPa (800 psig) initial air pressure in the batch mode or 7.0 MPa (1000 psig) total system pressure in the semibatch mode. An air flow of approximately 200 liters/hour (STP) was used in the semibatch mode. The mode of operation is also indicated in Table 1. The first ten coals in the two tables would meet the current EPA NSPS of 1.2 lb SO_2 per 10^6 BTU. Due to retention of sulfurous products in the ash during combustion, coals containing somewhat greater than 0.6 lb S per 10^6 BTU can be expected to meet NSPS (EPA, 1977). Reflecting the greater effectiveness of Oxydesulfurization for removing more pyritic than organic sulfur, all ten of the untreated coals had less than one percent organic sulfur.

Coals 11-17 in the two tables had moderate amounts of organic sulfur, up to 1.5 percent. Depending on the sulfur-retention properties of the ash, some of these coals might meet NSPS. Relatively small improvements in Oxydesulfurization processing could also bring these coals into compliance.

Coals 18-24 in the two tables had high organic sulfur contents, greater than 1.5 percent. For these coals significant improvement in organic sulfur removal would be necessary to bring them into compliance. However, due to their high organic sulfur contents, these coals have been used to

Weight Percent (Moisture Free)

#	Coal Seam	Mine	State	ASTM Rank	Total Sulfur Untr	Total Sulfur Tr[9]	Pyritic Sulfur Untr	Pyritic Sulfur Tr	Organic Sulfur Untr	Organic Sulfur Tr	BTU/lb (Dry) Untr	BTU/lb (Dry) Tr	Recovery (%)	lbsS/MM BTU Untr	lbsS/MM BTU Tr	Reaction Temperature (°C)
1	Black Creek	Natural Bridge Strip	AL	Hvb	1.22	0.65	0.42	0.16	0.69	0.47	13595	11694	94	0.90	0.56	180[5]
2	1	Peacock	CO	HvBb	1.88	0.67	0.95	0.10	0.60	0.57	13123	11001	92	1.45	0.61	200[5]
3	Imboden	Paramount Elkhorn No. 1 Strip	VA	HvAb	1.19	0.95	0.26	0.04	0.78	0.79	14273	13977	100	0.83	0.61	150[5]
4	Lower Freeport	Luciusboro Strip	PA	HvAb	2.83	0.75	2.03	0.02	0.65	0.68	12775	11944	99	2.22	0.63	180[5]
5	Lower Kittanning	2	PA	LvB	0.96	0.57	0.53	0.08	0.39	0.47	14590	13630	98	0.66	0.42	150[5]
6	Middle Kittanning	Congo Strip	OH	HvCb	1.08	0.60	0.26	0.04	0.78	0.55	11184	9648	89	0.96	0.62	180[5]
7	Mammoth	Storm King	MT	SbA	0.83	0.57	0.32	0.18	0.45	0.36	11770	10910	92	0.70	0.52	150
8	Pittsburgh	Bruceton	PA	HvAb	1.31	0.80	0.61	0.05	0.68	0.71	14170	13430	100	0.92	0.60	150
9	Upper Freeport	Baker	MD	Hvb	1.58	0.54	0.82	0.02	0.56	0.50	12642	11117	99	1.25	0.48	200[5]
10	Upper Freeport	Coal Junction Strip	PA	Hvb	2.14	0.63	1.37	0.04	0.49	0.50	11256	10213	95	1.90	0.62	200[5]
11	Brookville	Humphrey	PA	HvAb	4.20	1.17	3.06	0.13	1.11	1.01	13250	11346	96	3.17	1.03	180
12	Lower Freeport	West Valley Strip	PA	HvAb	4.14	1.04	3.09	0.22	1.01	0.78	13112	11395	98	3.15	0.91	180
13	Pittsburgh	Pitkulski Strip	PA	HvAb	1.67	0.89	0.71	0.03	0.82	0.83	11650	10890	100	1.43	0.81	160
14	Pittsburgh	No. 43 Strip	OH	HvAb	3.88	1.05	2.36	0.19	1.48	0.84	12657	10780	98	3.06	0.97	180
15	Pittsburgh	No. 43 Strip	OH	HvBb	3.01	0.98	1.93	0.16	1.05	0.80	12846	10787	98	2.34	0.90	180
16	Whitebrest	Lovilia No. 4	IA	HvCb	5.85	1.07	3.95	0.18	0.90	0.76	10870	9140	81	5.38	1.17	150[6]
17	Wyoming No. 9	Reliance	WY	HvCb	1.75	0.90	0.38	0.06	1.14	0.82	12410	11480	101	1.41	0.78	150
18	Bevier	No. 22 Strip	KS	HvAb	5.00	1.98	2.92	0.36	2.04	1.60	12203	12224	93	4.10	1.62	150
19	Illinois No. 5	3	IL	HvCb	3.34	2.03	0.92	0.12	2.06	1.82	12650	11600	90	2.64	1.75	150[7]
20	Illinois No. 6	River King	IL	HvBb	3.69	2.12	1.13	0.11	2.25	2.00	12190	10030	89	3.03	2.11	150[7]
21	Indiana No. 5	Enos	IN	HvBb	3.27	1.84	0.70	0.20	1.98	1.64	12340	10095	91	2.65	1.82	250[7]
22	4	Homestead	KY	HvAb	4.80	2.34	1.08	0.12	2.33	2.14	11380	11250	93	4.22	2.08	160
23	Minehall	Chrisney No. 1	IN	HvBb	5.65	1.43	3.01	0.10	1.53	1.22	11320	10230	85	4.99	1.40	200
24	Pittsburgh	Ireland	WV	HvAb	3.89	2.09	1.38	0.02	2.18	2.03	13390	12190	99	2.90	1.71	180

1. Uncorrelated Coal Seam 2. Obtained from Cambria Slope Preparation Plant 3. Information Not Available
4. Blend of Kentucky Seams No. 9, No. 11, No. 13 5. Modified Semicontinuous Mode (8-9 SCFH Air Flow) All others batch flow.
6. Four repressurizations in batch mode. 7. 1500 psig Initial Air in batch mode. 8 Untreated 9. Treated

Table I. - Summary of Coals Treated By Air/Water Oxydesulfurization

Moisture Free-Weight Percent

Coal[1]	Ash		Carbon		Hydrogen		Nitrogen		Oxygen	
	Untr[2]	Tr[3]	Untr	Tr	Untr	Tr	Untr	Tr	Untr	Tr
1	3.7	2.6	76.9	71.6	5.2	3.8	1.6	1.6	11.4	19.8
2	6.5	5.2	73.7	68.0	5.3	3.6	1.6	1.9	10.9	20.5
3	3.7	3.4	80.2	79.6	5.1	4.9	1.5	1.4	8.4	9.9
4	15.1	13.3	72.5	70.2	4.5	3.9	1.3	1.3	3.7	10.6
5	7.1	7.0	83.5	79.8	4.4	4.1	1.4	1.4	2.6	7.2
6	16.9	15.3	64.6	59.6	4.4	3.4	1.2	1.1	11.8	20.0
7	9.5	7.5	68.4	66.4	4.5	4.0	1.2	1.2	15.6	20.4
8	5.5	4.6	79.4	76.5	5.3	4.8	1.5	1.5	7.0	11.7
9	16.2	14.6	72.3	67.7	4.3	3.3	1.3	1.2	4.3	12.7
10	22.4	21.4	65.0	62.0	3.6	3.0	1.1	1.2	5.9	11.8
11	9.3	6.6	73.3	68.2	5.2	3.9	1.7	1.4	6.3	18.7
12	11.7	8.8	73.5	68.2	4.9	3.7	1.3	1.2	4.5	17.0
13	21.4	20.1	65.4	63.0	4.4	3.9	1.3	1.3	5.9	10.7
14	12.7	10.4	70.7	66.1	4.8	3.8	1.6	1.4	6.4	17.2
15	11.2	9.3	72.1	66.1	4.8	3.6	1.8	1.3	7.0	18.7
16	17.4	16.4	63.0	56.3	4.2	3.3	1.2	1.1	8.3	21.9
17	3.2	2.1	72.4	69.2	4.7	4.2	1.6	1.5	16.4	22.0
18	14.8	12.0	68.6	69.3	4.8	4.7	1.1	1.2	5.7	10.8
19	8.7	6.6	70.8	68.2	5.0	4.3	1.4	1.4	10.7	17.6
20	11.6	11.0	68.4	61.0	4.6	3.4	1.2	1.1	10.6	21.2
21	9.1	11.5	69.4	63.4	4.9	3.1	1.6	1.5	11.8	18.7
22	14.1	11.4	63.8	65.4	4.6	4.2	1.3	1.4	11.3	15.3
23	15.9	11.1	62.8	63.2	4.6	3.3	1.2	1.3	9.8	19.7
24	7.8	6.8	73.4	71.0	5.1	4.5	1.3	1.2	8.5	14.4

[1]See table 1. [2]Untreated [3]Treated

Table 2. - Summary of Coals Treated by Air/Water Oxydesulfurization

investigate the removal of organic sulfur by air/water oxidative desulfurization.

With increasing severity of operating conditions, increasing amounts of organic sulfur can be removed. However, the organic sulfur removal is accompanied by heating value losses for the coal. This is not surprising, since one would expect oxidation of organic structures to proceed at a rate at least comparable to that for oxidation and cleavage of some C-S bonds. An organic sulfur removal efficiency may be defined as the ratio of the differential increase in organic sulfur removal to the differential increase in heating value loss. So defined, this efficiency is equal to the slope of a line describing data as plotted in Figure 1. The data, from Table 1, exhibit considerable scatter. It should be remembered that, besides temperature variations, the data also represent coals of six different ranks, ranging from hvAb to sbA. Slagle and Shah (1978) prepared a similar plot for a single coal with variable temperature and observed a linear correlation superior to that shown in Figure 1.

The data in Figure 1 and those of Slagle and Shah (1978) were both for a single top size of coal, 200 mesh. Wheelock et. al. (1978) have presented data from which plots such as Figure 1 may be constructed for top sizes of 200 and 400 mesh. Such plots reveal a higher organic sulfur removal efficiency for the larger top size of coal. This finding suggests a surface effect. In the absence of such an effect the smaller particles would be expected to exhibit a higher

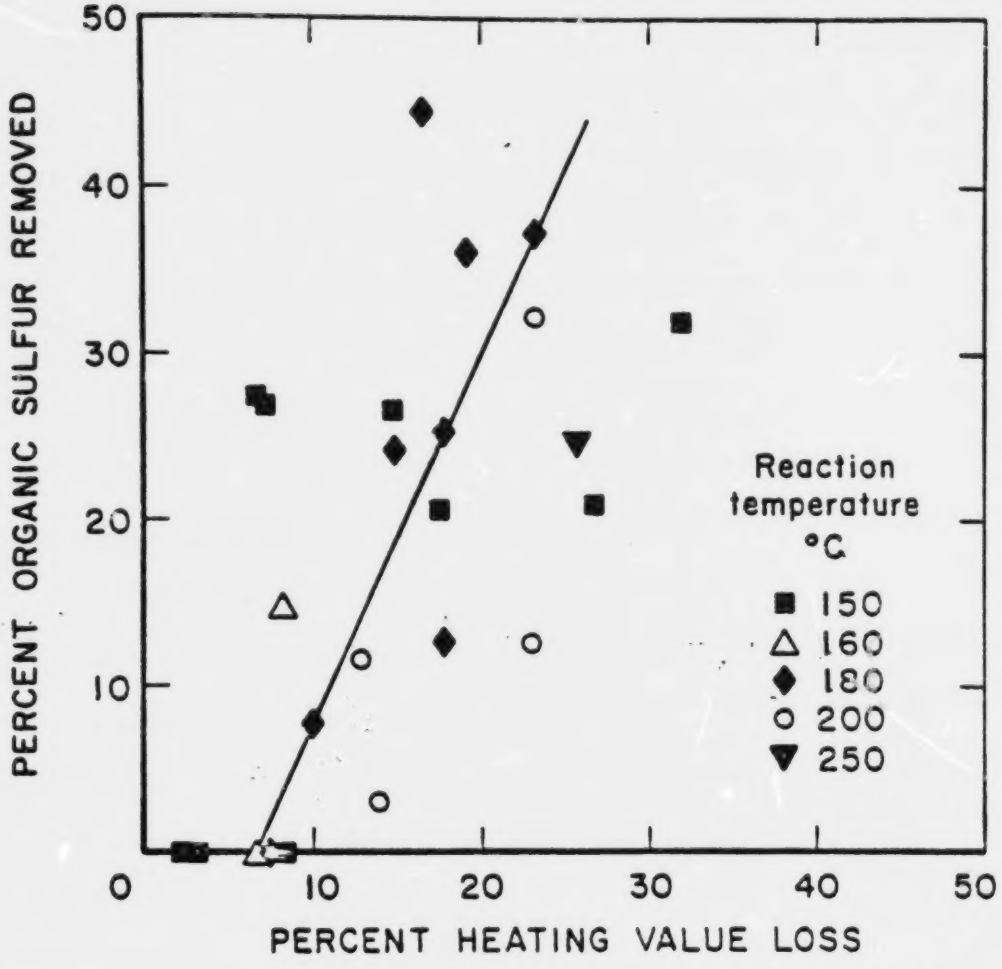

Figure 1-Organic sulfur removal efficiency.

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organic sulfur removal efficiency, since the leachant would have access to a larger fraction of all sulfur contained in the coal (Medieros and Peterson, 1976).

The data in Table 2 show an increase in oxygen content of coal due to processing. This effect is shown graphically in Figure 2, where moles of oxygen taken up by the coal per mole of carbon in the product coal is seen to increase with loss of heating value. Hydrogen and carbon in the coal decrease due to processing. The data in Table 2 are plotted in Figure 3. It is seen, for the range of heating value loss encountered, between zero and 30 percent, that hydrogen is preferentially removed from the organic matrix. Apparently heating value is lost both by consumption of the coal to final oxidation products, carbon dioxide and water, and by partial replacement of hydrogen by oxygen in the coal.

A beneficial side benefit of Oxydesulfurization treatment is reduction in the ash content of the coal. Part of the ash probably is dissolved in the sulfuric acid formed during reaction. Inspection of Table 2 shows a maximum ash reduction of 41 percent and an average reduction for all coals treated of 20 percent.

An interesting effect that has been observed with some coals is an apparent increase in organic sulfur with oxidative desulfurization treatment. An example is shown in Figure 4. The four experiments shown were made on a Lower Freeport coal according to the standard procedure for the continuous air feed mode, using the reaction conditions listed. Over 95

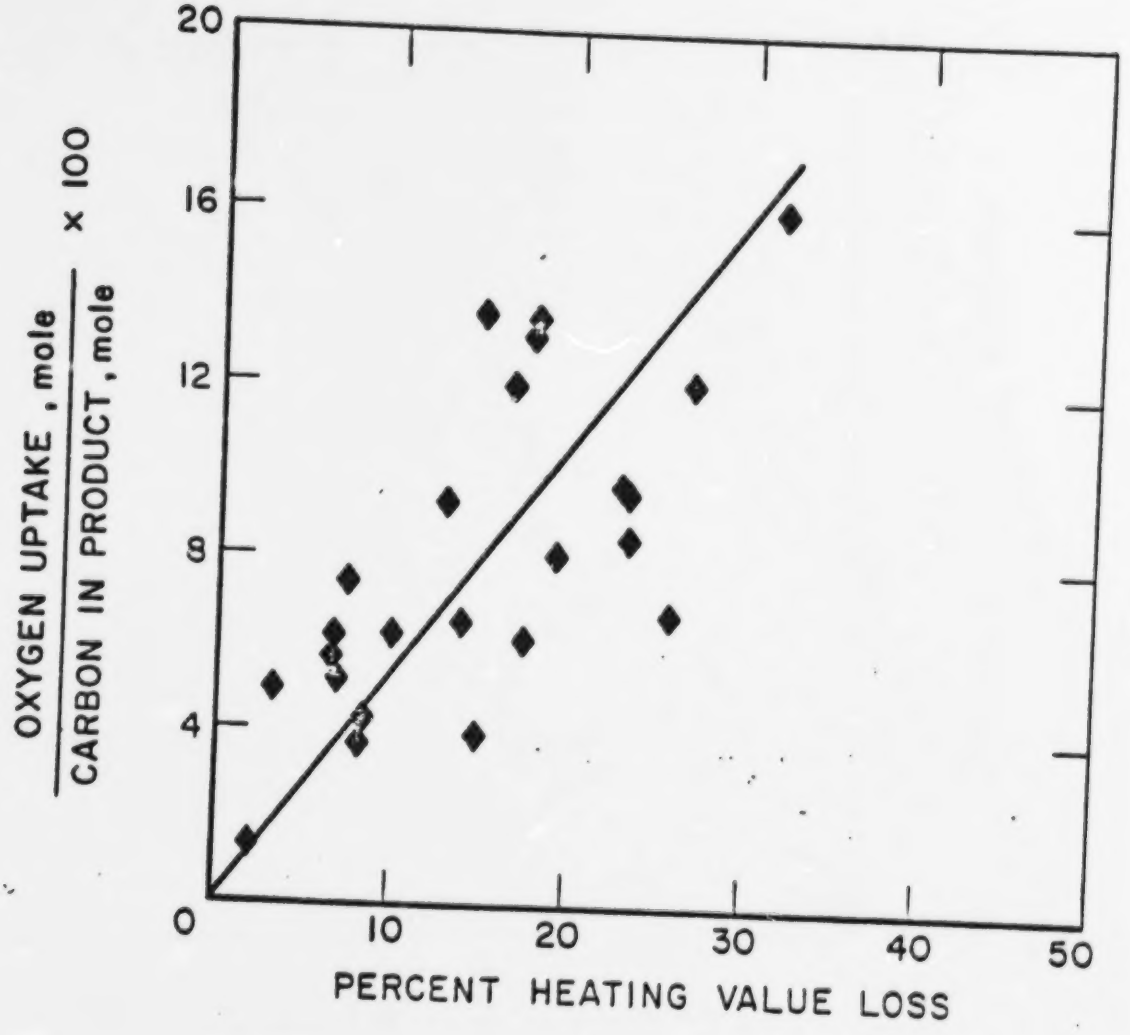

Figure 2-Oxygen uptake by coal due to treatment.

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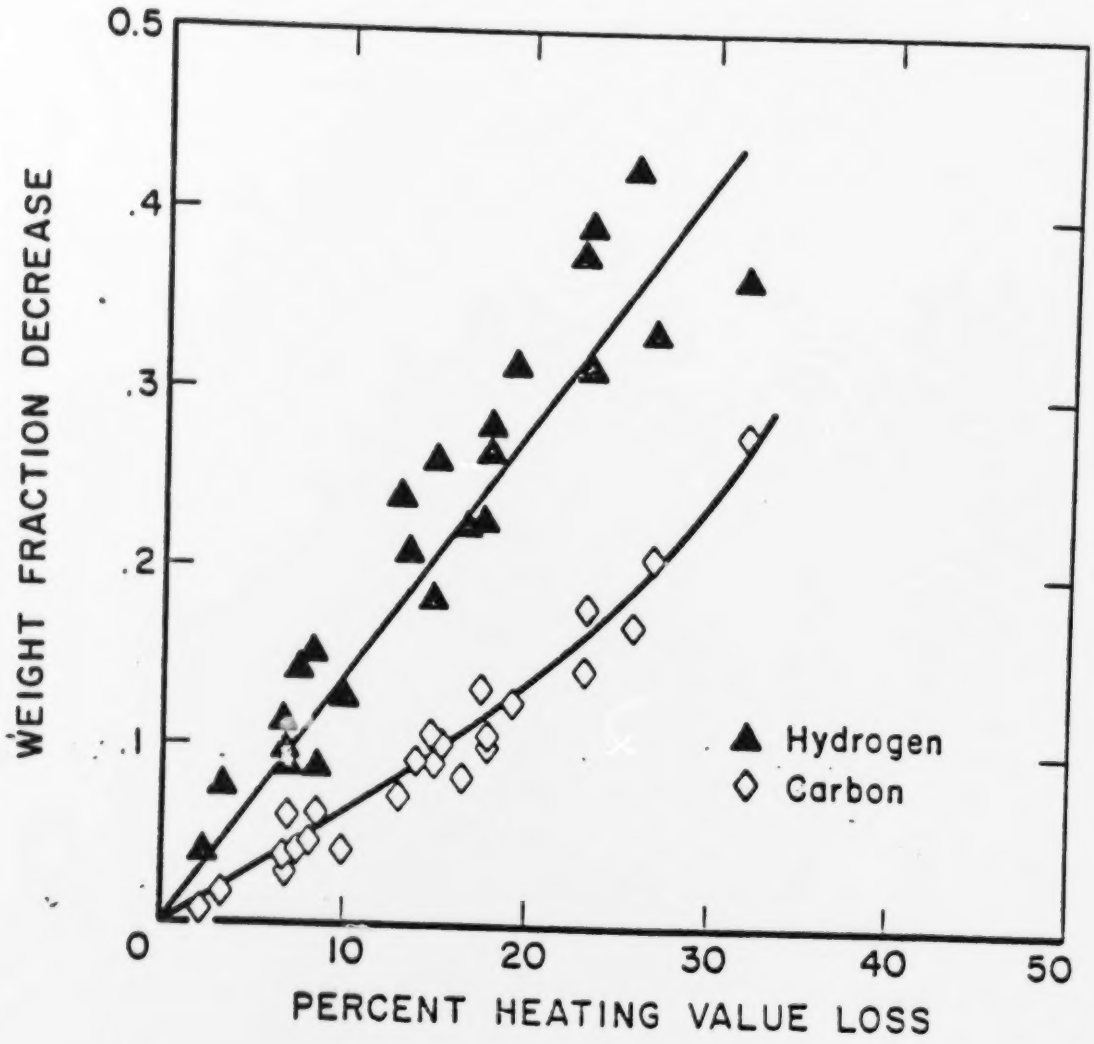

Figure 3-Carbon and hydrogen loss due to treatment.

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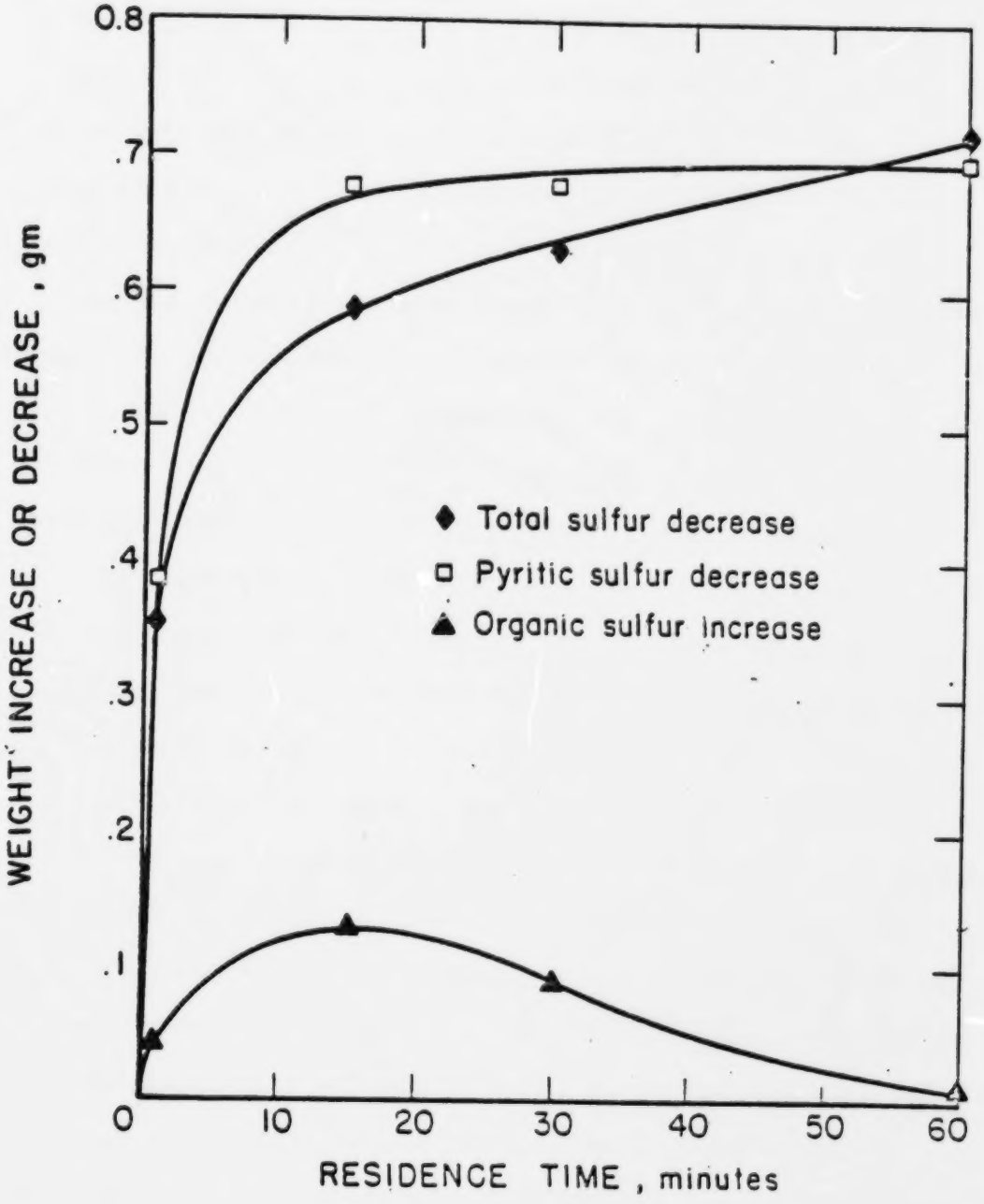

Figure 4-Apparent increase in organic sulfur with treatment. (Lower Freeport HVAb, 180°C, 1000 psig air, 35 g coal charge).

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percent of the pyritic sulfur is removed in the first 15 minutes, resulting in a total sulfur decrease of 60 percent. The organic sulfur registers an apparent increase, however, with the peak value at 15 minutes being 55 percent larger than the value for the untreated coal. With longer treat time the apparent organic sulfur decreases again, the value at one hour being close to the value for the untreated coal.

We do not believe that organic sulfur is created during processing, but rather that the anomalous results are an artifact arising from the analytical determination of organic sulfur by difference. The formation of jarosite-like basic salts is well known in hydrometallurgy. One such species is shown in Equation (4), as suggested by Vracar and Vukurovic (1970). Other solids can also be formed in our system, containing as it does ferrous, ferric, and sulfate ions, and smaller concentrations of other cations. Kwok and Robins (1973) have reviewed the formation of so-called thermal precipitates in aqueous solutions. Some of their data showing the formation of thermal precipitates in aqueous ferrous and ferric sulfate solutions are shown in Figure 5. For solutions with ferrous or ferric concentrations as indicated by a particular curve, a precipitate forms when the temperature and pH at 25° C place the system to the right of the curve. From calculated concentrations of ferrous/ferric ions and measured values of pH, we determine that the formation of thermal precipitates is possible in our system.

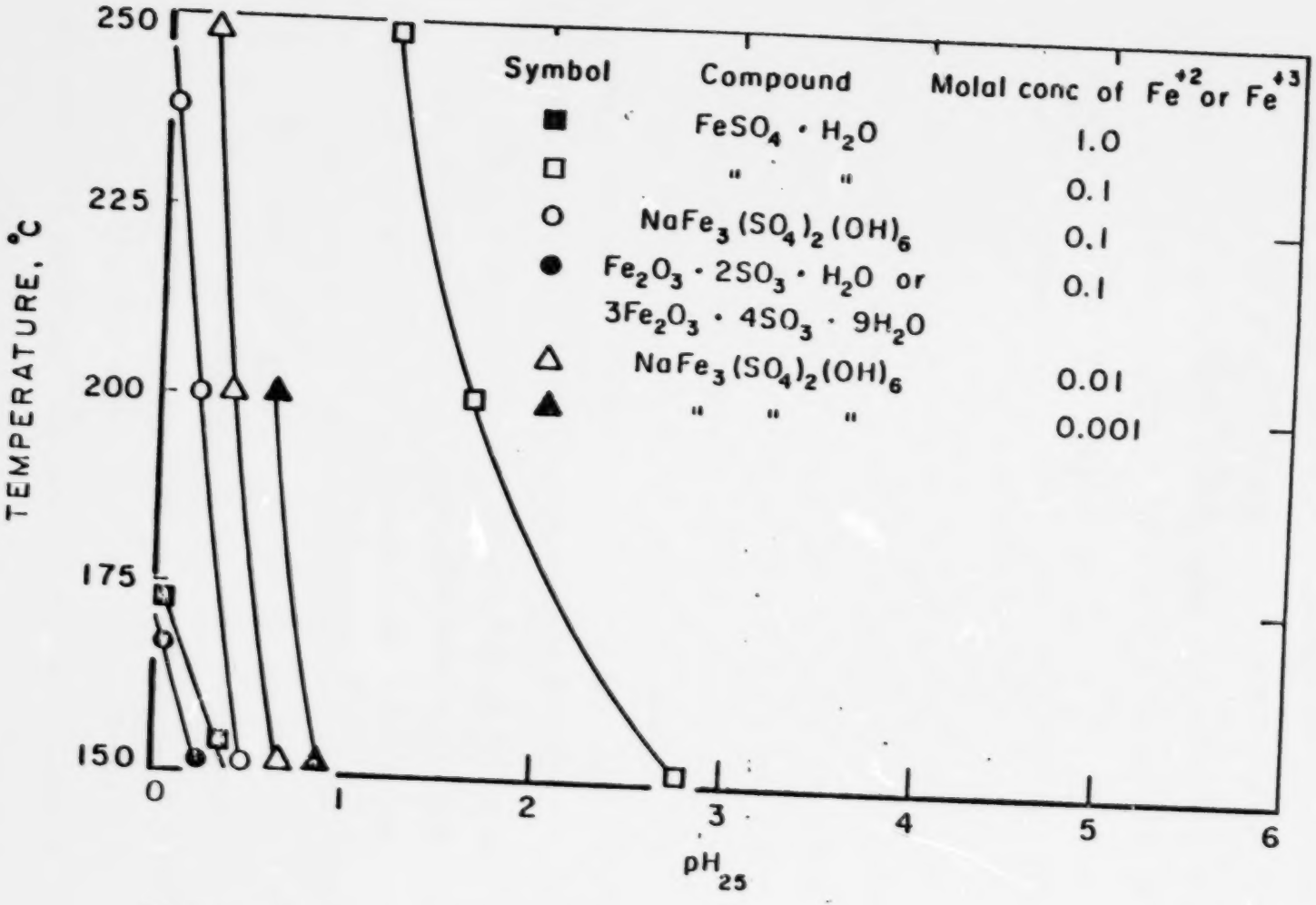

Figure 5 – Thermal precipitation of iron compounds in H_2SO_4 – H_2O (Na_2SO_4) system.

L-16225

We believe an explanation for Figure 4 is that jarosite-like compounds are formed in the early stages of reaction in which the pyrite is nearly completely consumed. The jarosites are not the most thermodynamically stable species at reaction conditions, but may form due to localized fluctuations in solution concentration in the vicinity of pyrite crystallites at the time they go into solution. Kept in contact with the leachant solution the jarosites digest to more stable forms, ferric oxide and sulfuric acid, which do not contain sulfur in the solid phase.

A thermal precipitate was formed in an experiment in which a model sulfur compound was subjected to Oxydesulfurization process conditions. X-ray diffraction analysis indicated that the precipitate was jarosite-like. X-ray fluorescence showed the major components of the precipitate to be iron and sulfur. No sodium was detected by this method or by atomic absorption. Therefore, the compound is not natrojarosite, for which the equilibrium precipitation temperature/acidity diagram is shown in Figure 5, but rather the basic sulfate as proposed by Vracar and Vucurovic (1970) in Equation (4). Analysis of precipitate by a Fisher sulfur analyzer indicated a sulfur content of 13.4 percent, which is close to the theoretical value of 13.34 percent for $Fe_3(SO_4)_2(OH)_5 \cdot 2H_2O$.

To test the possibility that jarosite-like compounds are responsible for apparent organic sulfur increase, a sample of an Upper Freeport seam coal was doped with the collected jarosite-like precipitate and submitted for analysis.

All of the sulfur in the doped coal, including the jarosite sulfur, was determined by the ASTM Eschka method, but only 86 percent of jarosite sulfur was reported as sulfate sulfur. None was reported as pyrite; the 14 percent balance, therefore, reported as organic sulfur. The organic sulfur in the doped sample, as a result, was 37 percent higher than normal.

TOWARDS A COMMERCIAL OXYDESULFURIZATION PROCESS

Work is continuing at the Pittsburgh Energy Technology Center to move chemical coal cleaning to a commercial reality. To this end a continuous reactor has been built and operated within the past months to conduct air/water oxidative desulfurization. A slurry bubble column reactor is employed, consisting of a vertical tube 2.22 cm inside diameter by 183 cm long. Preheated air and aqueous coal slurry are fed to the reactor cocurrently at the bottom. The treated coal slurry and exit gas are removed at the top.

Operation of the continuous reactor to date has been encouraging. Using an Upper Freeport coal (number 4 in Tables 1 and 2) at conditions of temperature and pressure as established in the autoclave work, some results were as follows. For a slurry space time of 6 minutes, the weight percent total sulfur was reduced from 1.82 in the feed coal to 0.87 in the product coal. With a slurry space time of 69 minutes the weight percent total sulfur in the product was 0.70. Slurry space time is defined as reactor volume divided by volumetric slurry feed rate.

A more complete account of operations with the continuous reactor will be made at a later time. Our experience to date however, has enabled us to develop a conceptual flow sheet for an Oxydesulfurization process. It is shown in Figure 6. The flow sheet can be considered in three sections: coal preparation, reaction and coal recovery, and acid neutralization.

In the coal preparation section run of mine coal is subjected to a number of conventional physical coal cleaning operations to remove white rock and some separable pyrite. These cleaning operations employ a grizzly, rotary breaker, and jig plant. The physically cleaned coal is stored in a day bin before being sent to a ring mill and ball mills for grinding. The ground coal is slurried, preheated, and fed to a slurry bubble column reactor. Also fed to the reactor is compressed air. Spent air/ steam from the reactor is used in a turbine expander to supply some of the power required for air compression. Product coal from the reactor is filtered, dried, and is then ready for use.

Effluent water from the reactor, containing sulfuric acid, is neutralized. Shown on the flowsheet are steps for the grinding and storage of limestone. The acid water and limestone are combined in the neutralization tank. By-product gypsum is removed by filtration, and the treated water is recycled to the slurry preparation tank.

The flow sheet illustrates the complementarity of physical and chemical coal cleaning methods. Relatively

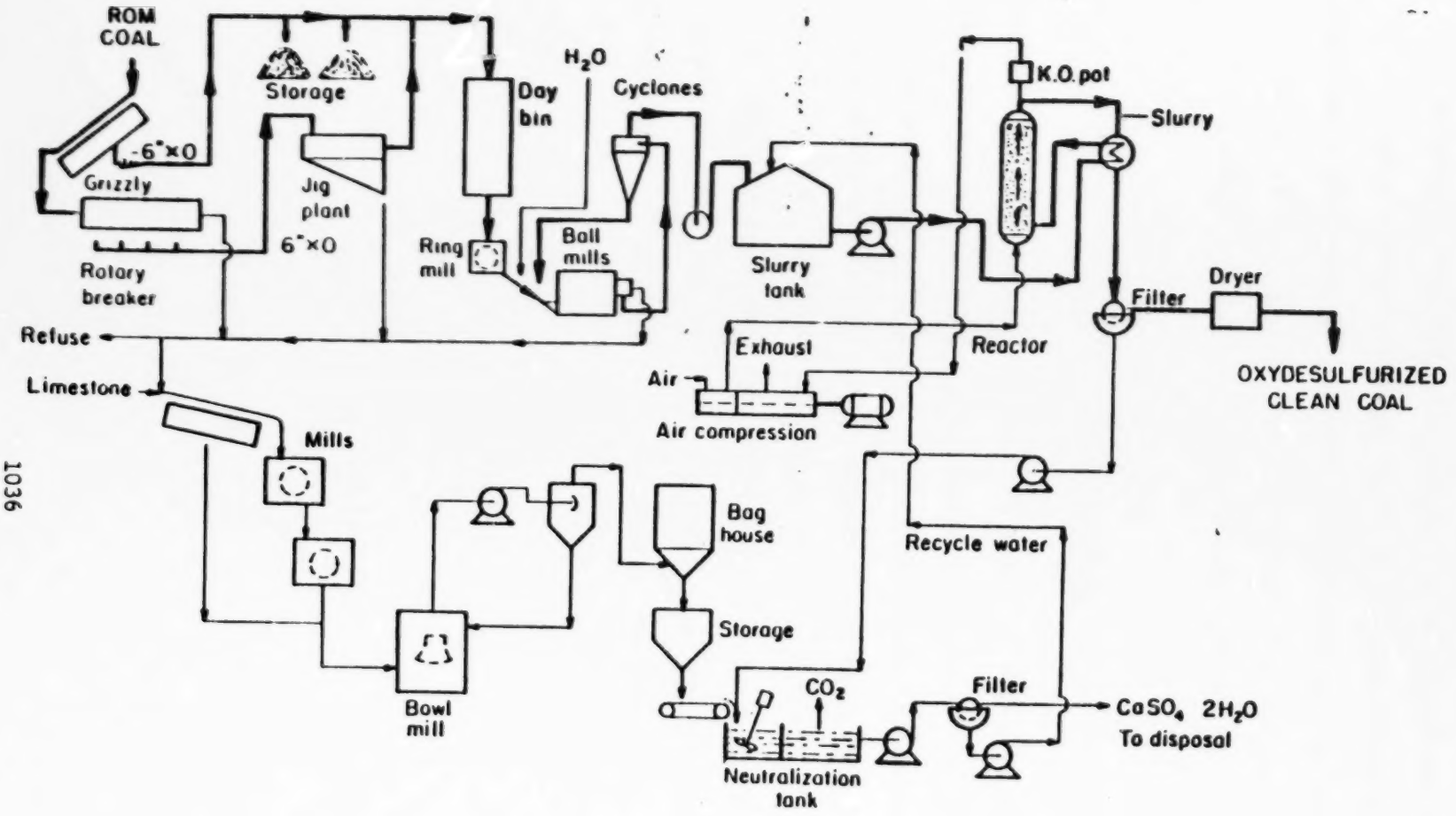

Figure 6 - Oxydesulfurization process

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more washable coals would have a higher fraction of sulfur removed in the physical preparation section; those less washable would have a more sulfur removed by chemical cleaning. Also apparent is the simplicity of the process. Air, water, and limestone are the only materials required to treat the coal.

ACKNOWLEDGMENTS

The authors wish to thank Forrest Walker and the Pittsburgh Coal Analysis Laboratory for performing the necessary analyses and the Chemical and Instrumental Analysis Division at the Pittsburgh Energy Technology Center for the various analyses on the gas, liquid and residue samples. We would also like to thank Harry Ritz, who is responsible for the construction of the continuous slurry unit now in operation and for preparing the process flow diagram, and Robert B. LaCount for his work in the early part of the research program.

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